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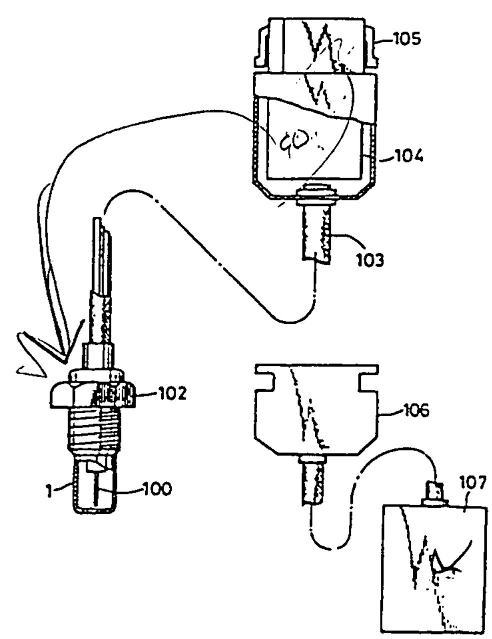
(54) Air/fuel ratio sensor.

(57) A detection circuit (200, 300, 400, 500) of a sensor (100) for producing an output proportional to the oxygen concentration in exhaust gas is incorporated in a satellite module (104) integrally connected to the sensor (100) with a cable (103). The satellite module (104) is separable from a microcomputer by connector means (105). The sensor (100) and the module (104) are joined integrally so that the sensor characteristics can be adjusted as desired.

FIG. 6



EP 0 120 423 A1

Specification

Title of the Invention

Air/Fuel Ratio Sensor

Background of the Invention

This invention relates to a sensor for detecting engine conditions, and more specifically to an air/furl ratio sensor for detecting the oxygen concentration in exhaust gas by which to ascertain the mixing ratio of air to fuel fed to the engine.

Conventional air/furl ratio sensors, as disclosed for example in U.S. Patent No. 3,851,929, comprise a solid electrolyte layer which conducts oxygen ions and electrodes provided on opposite sides of the electrolyte, one of the electrodes being exposed to the atmosphere so that a voltage proportional to the oxygen concentration in the exhaust gas encountered can be produced across the electrodes.

With these sensors, which are designed to detect exhaust gas conditions on the basis of the atmospheric oxygen concentration as the only reference, it has been impossible to alter the exhaust detection standard as desired. The conditions have remained unchangeable except for mere stepwise changes in output under theoretical air/fuel ratio conditions.

The existing sensors have inherent dispersions in their characteristics that originate from the fabrication of their elements. Since the dispersions cannot be compensated for, the current practice is to use only the sensors conforming to

specific standards. Nevertheless, it is still difficult to obtain sensors of characteristics uniform throughout; some ununiformity is inevitable. The dispersion in the characteristics of the air/fuel ratio sensor results in scattering detection results, and the existing sensors cannot be expected to detect oxygen concentrations invariably with acceptable accuracy.

Summary of the Invention

The present invention is aimed at providing an air/furl ratio sensor capable of detection with good accuracy even if there may be any dispersion in its characteristics.

In accordance with the invention, good detection accuracy is attained despite a dispersion in sensor characteristics by providing a sequencer for air/fuel ratio (λ) detection on an integrated-circuit substrate independently of a microprocessor and thereby making characteristic adjustments for the particular sensor.

Brief Description of the Accompanying Drawings

Fig. 1 is a sectional view of an air/furl ratio sensor for use in the present invention;

Figs. 2(a) to (c) are, respectively, plan, sectional, and rear views of the sensor shown in Fig. 1;

Fig. 3 is an exemplary driving circuit diagram for the sensor of the invention;

Figs. 4 and 5 are time charts for the sequential operation

of the driving circuit shown in Fig. 3;

Fig. 6 is a partly sectional perspective view, showing the general construction, of an embodiment of the invention;

Fig. 7 is a circuit diagram of the embodiment shown in Fig. 6;

Figs. 8 and 9 are λ-detection circuit diagrams;

Fig. 10 is a pumping circuit diagram; and

Fig. 11 is a heater circuit diagram.

Detailed Description of the Preferred Embodiment

An embodiment of the invention will now be described. A structure as shown in Fig. 1 has been invented which comprises a solid electrolyte base 3, a first electrode P_1 and a second electrode P_2 both of which are formed on one side of the base but are electrically separated from each other, and a third electrode P_3 formed on the other side of the base, opposite to both the first and second electrodes, in such a manner that a current is flown through the third electrode to heat the solid electrolyte. The solid electrolyte base is made, for example, of stabilized zirconia by the green sheet technique or the like. The electrolyte material is mixed with a stabilizer such as yttria or calcia and a sintering assistant such as alumina or silica.

A typical arrangement of an air/furl ratio sensor incorporating the structure of Fig. 1 is illustrated in Figs. 2(a), (b), and (c). Fig. 2(a) is a plan view, Fig. 2(b) a sectional

view, and Fig. 2(c) a bottom view. On the main surface of the solid electrolyte base 3 is formed an electrically conductive layer, for example, a porous film of a platinum metal having a catalytic capacity, by printing and firing of a thick-film, noble-metal conductive paste over the entire surface of the base. A continuous groove 5 is formed in a comb-like fashion in the conductive layer thus formed to sever it into a first electrode P_1 and a second electrode P_2 electrically insulated from each other. Near one end of the solid electrolyte base 3, there are formed a bonding pad B_1 on the first electrode P_1 and another bonding pad B_2 on the second electrode P_2. These bonding pads are formed, for example, by printing and firing a platinum conductive paste. The main surface of the electrolyte base 3, including the first and second electrodes P_1, P_2, is completely covered with a porous ceramic layer 6. This layer 6, which protects the electrodes from direct exposure to exhaust emissions, is formed of a material permeable to exhaust gases, catalytically active, and which has substantially the same coefficient of thermal expansion as that of the solid electrolyte base 3.

On the rear side of the solid electrolyte base 3 is formed a conductive layer, as shown in Fig. 2(c), by printing the entire surface with a thick-film, noble-metal conductive paste of gold or the like which is slightly catalytic or non-catalytic and resistant to heat, with subsequent firing of the print.

Fine-line grooves are formed across the base, from end to end, in a fine-toothed comb pattern. On one end portion of the conductive layer, severed by a groove into two, there are provided two bonding pads B_{31}, B_{32}, one for each. The rear side of the solid electrolyte base, with a third electrode P_3 thus formed, is completely covered with a gastight ceramic layer 7. This coat is formed of a chemically stable, highly insulating ceramic composition based on glass into a closed-cell or non-porous structure. The coat of such a chosen material keeps exhaust gases out of contact with the third electrode P_3 and prevents any change in the oxygen ion concentration at the interface between the third electrode P_3 and the solid electrolyte base 3 due to the ion diffusion into exhaust gases during the movement of the oxygen ions between the second and third electrode P_2 and P_3.

The air/furl ratio sensor with the structure described above develops between the first and third electrodes P_1 and P_3 an output voltage directly proportional to the oxygen concentration ratio at the interface between the respective electrodes and the solid electrolyte base 3. When migration of oxygen ions takes place between the second and third electrodes P_2, P_3, replacement of oxygen ions with oxygen gas is carried out along the interface of the second electrode P_2 with consequent diffusion of the oxygen gas through the porous ceramic layer 6 into the exhaust gases.

It is known generally that where the third electrode P_3 possesses a greater catalytic capacity than the first and second electrodes P_1, P_2, its output voltage sensitivity is much enhanced. It has also been known that the accuracy of air/fuel ratio detection is improved when the third electrode P_3 is isolated from exhaust gas and the partial pressure of oxygen at the interface is totally ascribable to the movement of oxygen ions. For these reasons the third electrode P_3 and the solid electrolyte base 3 are desired to provide as large surface areas as possible for the interface and be joined in intimate contact with each other both mechanically and electrochemically.

The air/furl ratio sensor of the invention is manufactured, for example, in the following way. A single wafer is furnished which measures 60 x 60 mm for separation into 72 chips, each 5 x 10 mm. The wafer is only 0.25 mm thick to economize on power for scribing with a laser and also to limit the heating power required for constant-temperature control at 300°C in exhaust gas to 4 W or less. The wafer is formed with a film of platinum for the first and second electrodes on one side and a film of gold for the third electrode on the other side, both by sputtering to a film thickness of 1.5 μm each. After a heat treatment the platinum film is coated with stabilized zirconia and the gold film with a 50:50 mixture of silica and stabilized zirconia by high-frequency sputtering. The protected films thus formed, 0.5 to 1.0 μm thick, are heat treated for

reinforcement. These protective films are not formed on bonding pad portions which are masked to evade coating. Then, the coated wafer is separated by the laser into chips. Stainless steel leads are connected to the bonding pads of each chip by wire bonding, and the chip is attached to a plug, and then stabilized zirconia is plasma sprayed on the both sides.

Driving of the air/furl ratio sensor fabricated in this way will be described below with reference to Fig. 3. A heating power supply 8 for constant-temperature control is connected between the bonding pads B_{31}, B_{32} on the rear side of the solid electrolyte base, and negative feedback control is effected with the bonding pad B_{32} as the base to maintain the resistance between the two electrodes constant. A constant-current power supply 9 is connected between the bonding pads B_2 and B_{32} so that negative feedback control can be effected with the pad B_{32} as the base to permit predetermined oxygen ion flow through the solid electrolyte base 3 between the second and third electrodes P_2 and P_3. A detection amplifier 10 is connected between the bonding pad B_1 of the first electrode P_1 and the bonding pad B_{32} of the third electrode P_3 to amplify air/fuel ratio signals to a desired level. The heating power supply 8 for constant-temperature control, constant-current power supply 9, and detection amplifier 10 are operated in a predetermined sequence by a sequencer 11.

The sequencer itself operates in the following manner.

As indicated in Fig. 4, oxygen ions from the second electrode P_2 pass through the solid electrolyte base, and the oxygen concentration is measured by the first electrode P_1 for periods of time in suitable proportions on a time-sharing basis. The heating current from the third electrode P_3 is interrupted when necessary during the measurement of the oxygen concentration.

Also, as shown in Fig. 5, oxygen ions are moved between the third electrode P_3 and the first and second electrodes P_1 and P_2 at alternate time intervals. Oxygen concentration measurements are alternately made by the first and second electrodes during the periods in which the oxygen ion movement does not occur.

In this way the sensor can be directly heated by the third electrode P_3 which functions also as a heater, and can be actuated immediately following the cold start of the engine.

Fig. 6 illustrates an embodiment of the present invention. As shown, a sensing element 100 enclosed in a protective tube 101 is fitted to a plug 102 by which it can be attached to the exhaust pipe of an automotive engine not shown. This sensing element 100 is the sensor already described with reference to Fig. 1. It is connected through a cable 103 to an IC substrate 104, which in turn has a connector 105 by means of which it is connected to a microprocessor 107.

The interconnected relations of the components in Fig. 6 are represented by a circuit diagram in Fig. 7.

The sensor 100 has a first electrode P_1 and a second electrode P_2 both of which are formed on one side, or the main surface 100A, and electrically insulated from each other. The two electrodes are formed by printing and firing a thick-film, noble-metal conductive paste on the surface and then grooving the printed surface in a comb-like fashion. Close to one end of the solid electrolyte base, there are provided a bonding pad B_1 on the first electrode P_1 and another bonding pad B_2 on the second electrode P_2. The main surface 100A of the sensor 100, including the first and second electrodes formed thereon, is entirely covered with a porous protective film.

On the rear side 100B of the sensor 100 is provided a third electrode P_3, which is a conductive layer extending in a fine=line comb-like pattern from end to end, by printing and firing a thick-film, noble-metal conductive paste of gold or the like which is slightly catalytic or non-catalytic over the entire surface and then forming a groove in a comb-like fashion. Near one end of the rear side where the conductive layer terminates, there are formed bonding pads B_3, B_4. The rear side 100B of the sensor 100, including the third electrode P_3, is completely covered with a gastight protective film.

To the bonding pad B_1 on the main surface 100A of the sensor 100 is connected a λ-detection circuit 200, which detects the value of air/fuel ratio λ. Another input terminal of this detection circuit is connected to the bonding pad B_4 on the

rear side 100B. A signal terminal S_1 of the λ-detection circuit 200, and the circuit is supplied with power via source terminals V_1, V_2 of the connector 105. To the bonding pad B_2 on the main surface 100A is connected a pumping circuit 300, another input terminal of which is connected to the bonding pad B_4 on the rear side 100B. The pumping circuit 300, also connected with the source terminals V_1, V_2, functions to provide a reference oxygen concentration at the time of oxygen concentration detection. A heater circuit 400 is connected between the bonding pads B_3, B_4 on the rear side 100B of the sensor 100, so that entire rear side can serve as a heater to heat the sensor. The heater circuit 400 is connected to the terminals V_1, V_2 of the connector 105 for energy supply. A sequencer 500 for controlling the λ-detection circuit, pumping circuit 300, and heater circuit 400 is connected to the individual circuits and also to the source terminals V_1, V_2. All the circuits 200, 300, 400 combine with the sequencer 500 to constitute an IC substrate 104.

The λ-detection circuit 200 is represented by a circuit diagram in Fig. 8. The bonding pad B_1 is connected to the "-" terminal of an operational amplifier 201 around which negative feedback is applied via a resistor 202. To the "+" input terminal of the amplifier is connected the bonding pad B_4. The output terminal of the amplifier 201 is connected through a resistor 203 to the "-" terminal of another operational ampli-

fier 204 whose "-" input and output terminals are bridged via a resistor 205. In this arrangement a voltage as divided by resistors 206 and 207 into two is input to the "+" input terminal of the operational amplifier 204. The other ends of the resistors 206 and 207, remote from the input terminal, are connected, respectively, to the terminals V_2 and V_1. The output terminal of the operational amplifier 204 is connected to a signal terminal S_1.

With the foregoing connections the λ-detection circuit 200 is designed to detect an air/fuel ratio. The resistor 207 is finely adjusted by laser trimming or the like to compensate for the offset voltage of the detection circuit. Also, the resistor 203 is trimmed for gain control. The operational amplifier 204 outputs a voltage corresponding to the air/fuel ratio encountered (for example, based on a reference voltage of 0.65 v when $\lambda = 1$).

When the λ-detection circuit 200 has only to perform the detection by on-off switching at every theoretical air/fuel ratio point, it may take a simpler form as in Fig. 9. Here the bonding pad B_1 of the sensor 100 is connected to the "+" input terminal of the operational amplifier 210, the "-" input terminal of which is connected with resistors 211 and 212. The opposite ends of the resistors 211 and 212 are connected, respectively, to the source terminal V_2 and the bonding pad B_4 of the sensor 100. The output terminal of the amplifier

210 is connected to the signal terminal S_1. The resistor 212 is trimmed so that it allows the operational amplifier 210 to give a low output when the air/fuel ratio of given exhaust gas exceeds the theoretical level due to any dispersion in the characteristics of the sensor 100. Thus, a dispersion in the characteristics arising from the fabrication of the sensor 100 can be adequately compensated for by finely adjusting the resistor 212 by laser trimming or other similar technique.

The pumping circuit 300 is constructed as in Fig. 10. A resistor 301 is connected to the bonding pad B_2 of the sensor 100 and also, at the both ends, to an operational amplifier 302. The other end of the resistor 301 is connected to the emitter of a transistor 303, the collector of which is connected to the source terminal V_2. The base of the transistor 303 is connected to the output terminal of an operational amplifier 304, which in turn has an input terminal connected to the output terminal of the amplifier 302 and another input terminal connected to a resistor 305 and the cathode of a zener diode 306. The other end of the resistor 305 is connected to the source terminal V_2. The anode of the zener diode 306 is connected to a grounding terminal V_1.

In the arrangement described, a given current is supplied to produce a reference O_2 concentration under the control by the sequencer 500. The current is detected at the both ends of the resistor 301 and the detected value is fed back to the

transistor 303 so as to ensure the flow of a constant current through the sensor. Pumping by this circuit determines the reference O_2 concentration, and the λ value is detected by the λ-detection circuit at the next stage. This pumping current is governed by the resistor 301. By trimming the resistor 301 by laser a desired pumping current is obtained.

The heater circuit 400 is built as shown in Fig. 11. To the bonding pad B_3 of the sensor 100 are connected a resistor 401 and an operational amplifier 402. The output terminal of the amplifier 402 is connected through a resistor 403 to the base of a transistor 404, the emitter of which is connected to the end of the resistor 401 farther from the bonding pad. The collector of the transistor 404 is connected to the terminal V_2 of the connector 105. The other input terminal of the operational amplifier 402 is connected between resistors 405 and 406, the other ends of the resistors 405 and 406 being in connection, respectively, with the terminal V_2 of the connector 405 and the grounding terminal V_1.

The heater circuit 400, built in this way, is designed to heat the rear side 100B of the sensor 100. The rear side 100B is supplied with a sufficient current to attain a desired resistance (because the resistance is dependent on the temperature). The current to be supplied to the rear side is dictated by the current to be fed back to the transistor 404, and the amount of the feedback by the resistance of the resistor 406

connected to the operational amplifier 402. Hence, trimming the resistor 406 determines the temperature of the rear side 100B. In this way the characteristic dispersion of the sensor 100 can be corrected by adjusting the resistor 406 by laser trimming or other similar technique.

The dispersion can be adequately compensated for, in the manner described in connection with the embodiment of the invention, by separating all of the λ-detection circuit in which the element-derived dispersion in characteristics of the sensor 100 results in detection accuracy dispersion, the pumping circuit, and the heater circuit from the computer, and packaging them in an IC substrate 104 as an intelligent module.

In the embodiment being described, the sensor and the IC substrate are integrally connected with a cable and, in case of any sensor malfunction or failure, they can be replaced together as an interchangeable unit. There is no necessity of looking for a new sensor with characteristics matching those of the processing module. All the components can be preadjusted and accordingly the maintenance is markedly simplified.

As has been described thus far, the present invention permits detection with good accuracy despite any dispersion the sensor may have in its characteristics.

Claim

An air/fuel ratio sensor comprising a sensor (100) for producing an output proportional to the oxygen concentration in exhaust gas or other gas, and a satellite module (104) connected to said sensor (100) with a cable (103), said satellite module (104) containing a detection circuit (200, 300, 400, 500) which receives output signals from said sensor and standardizes each said signal to be a signal corresponding to the oxygen concentration, said module (104) being electrically and mechanically connectable to, and disconnectable from, a control unit including a microcomputer by connector means (105).

FIG. 1

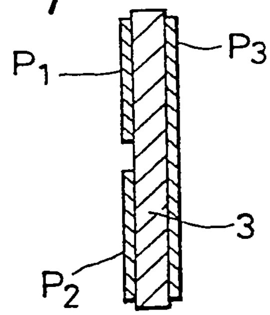


FIG. 2(a)

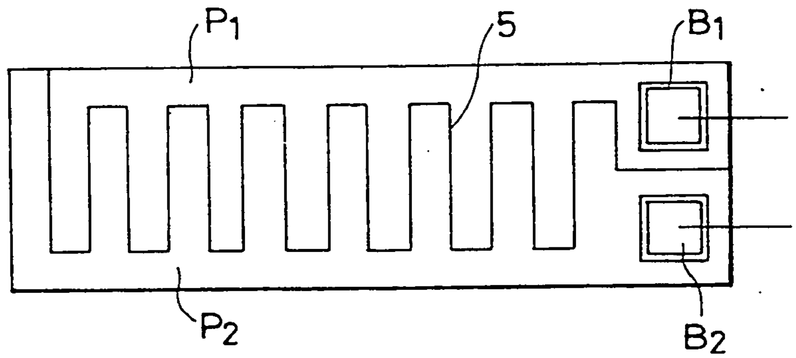


FIG. 2(b)

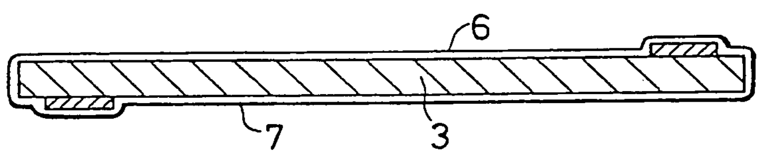


FIG. 2(c)

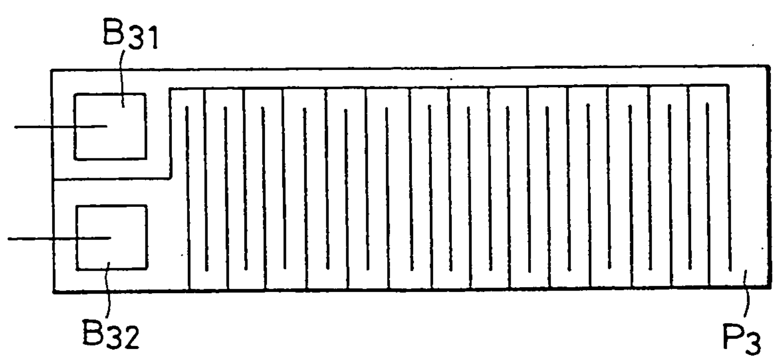


FIG. 3

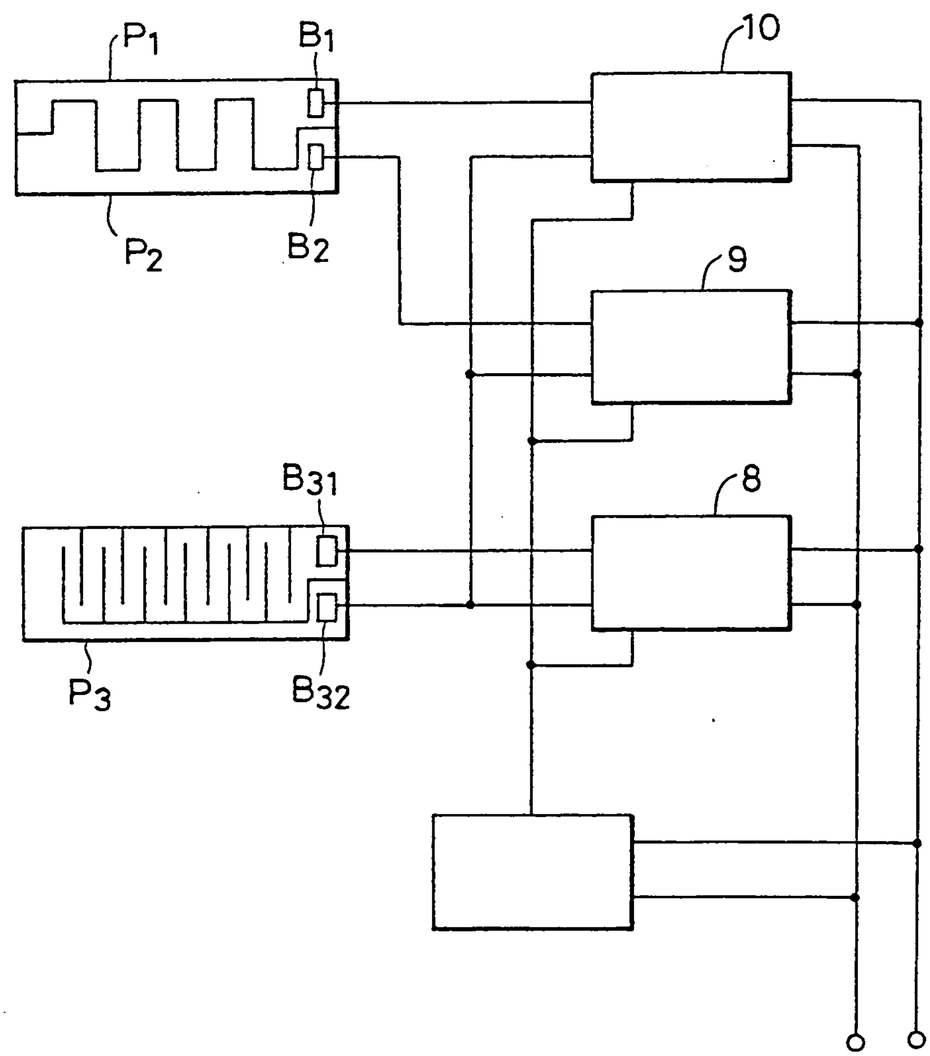
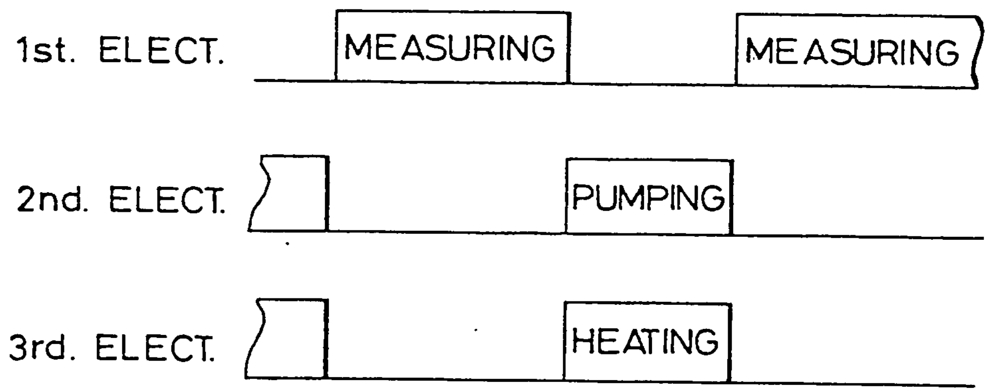


FIG. 4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MEASURING
MEASURING
2nd. ELECT.
PUMPING
3rd. ELECT.
HEATING

FIG. 5

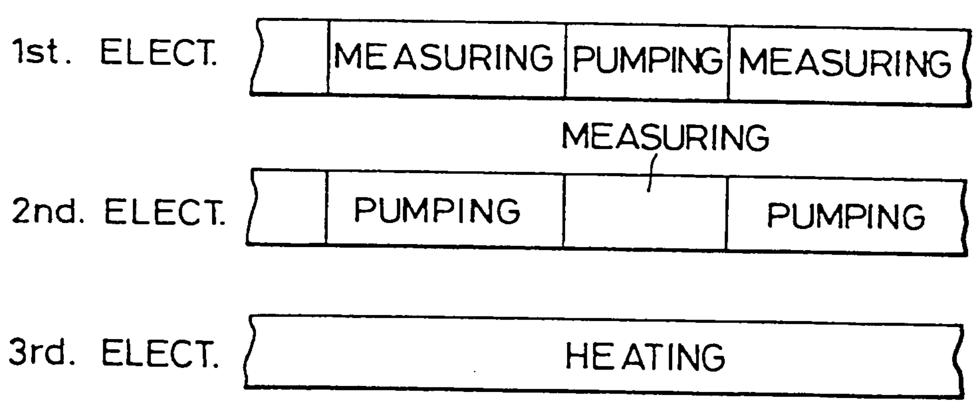

1st. ELECT.
MEASURING
PUMPING
MEASURING
MEASURING
2nd. ELECT.
PUMPING
PUMPING
3rd. ELECT.
HEATING

FIG. 6

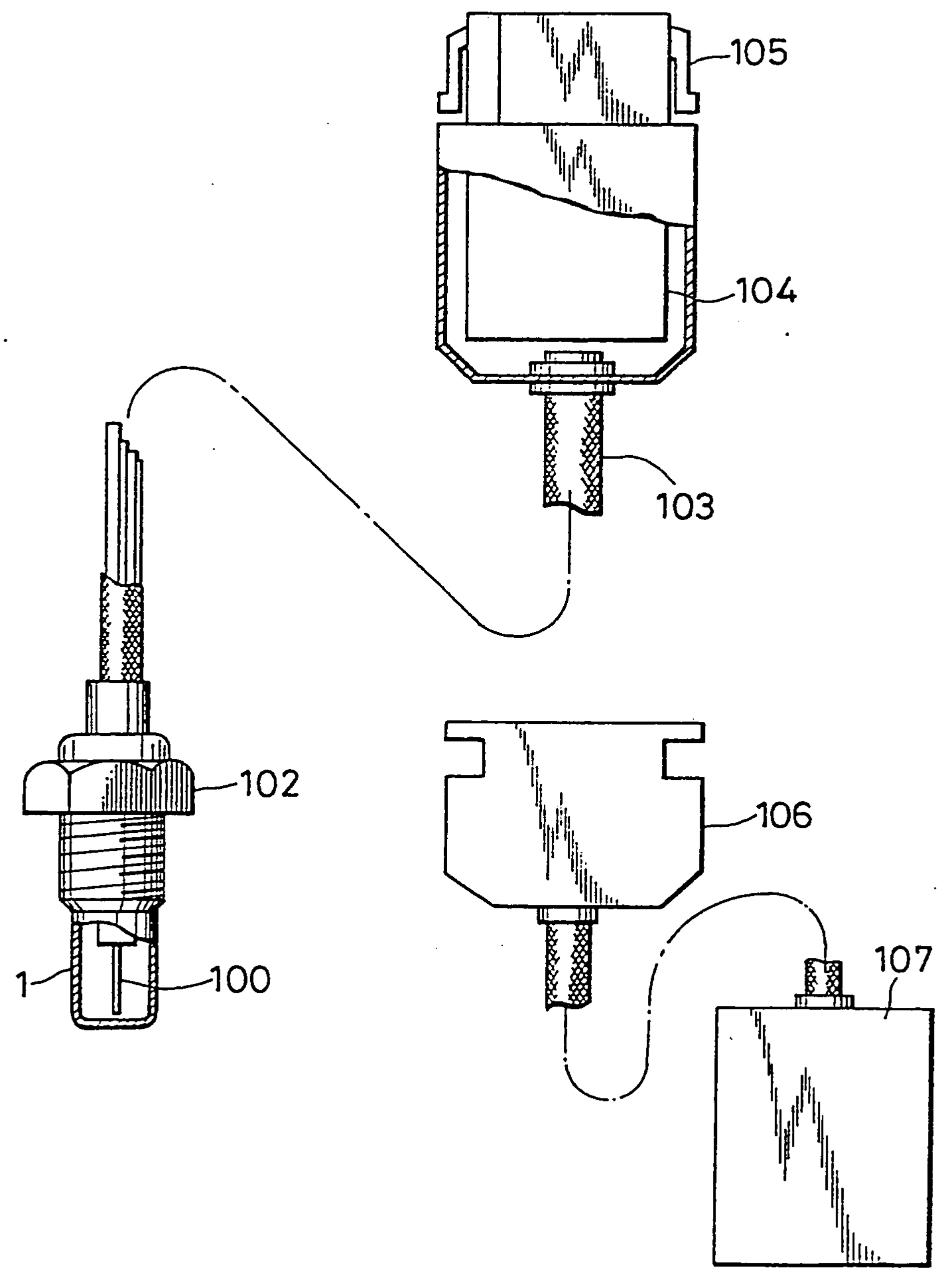


FIG. 7

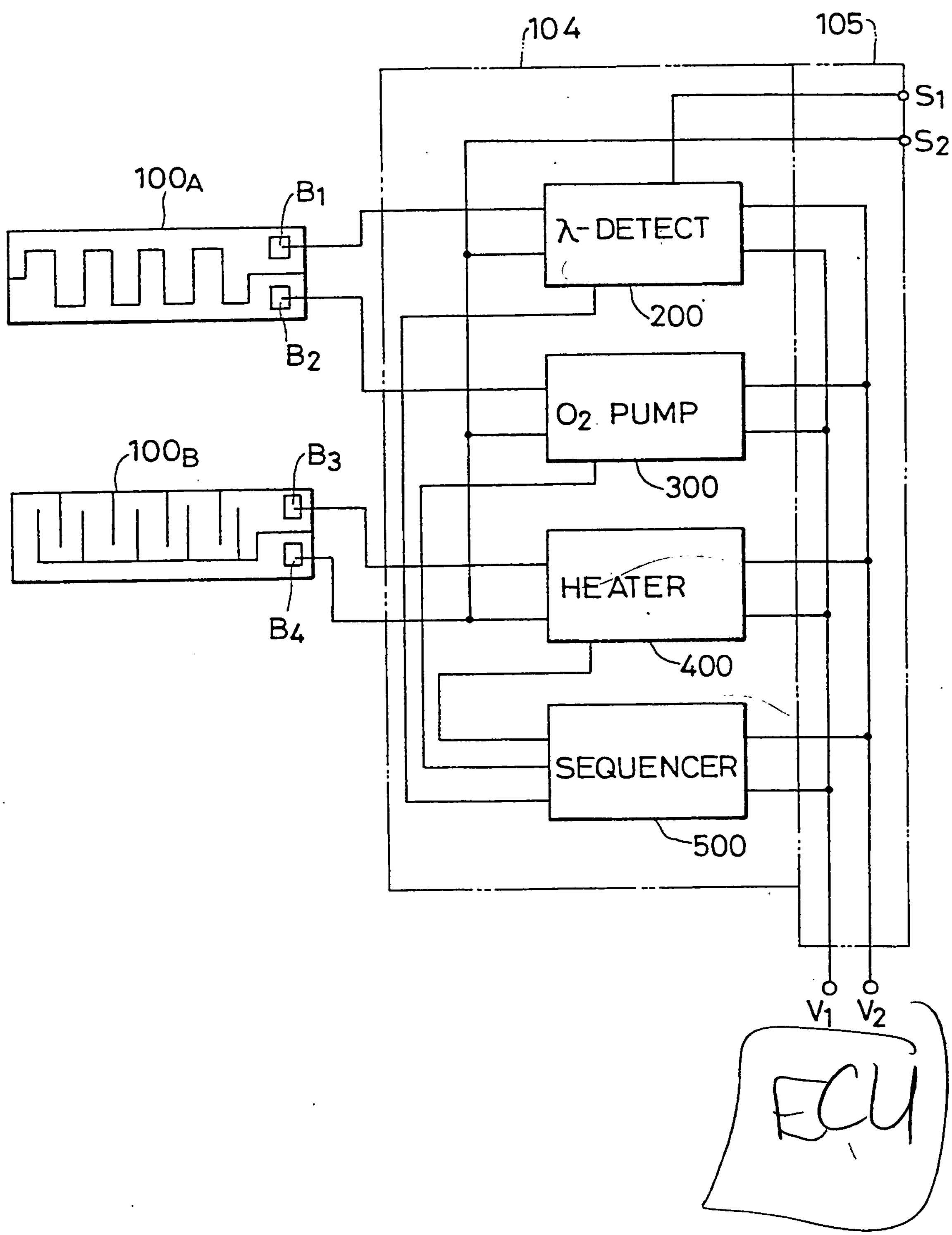
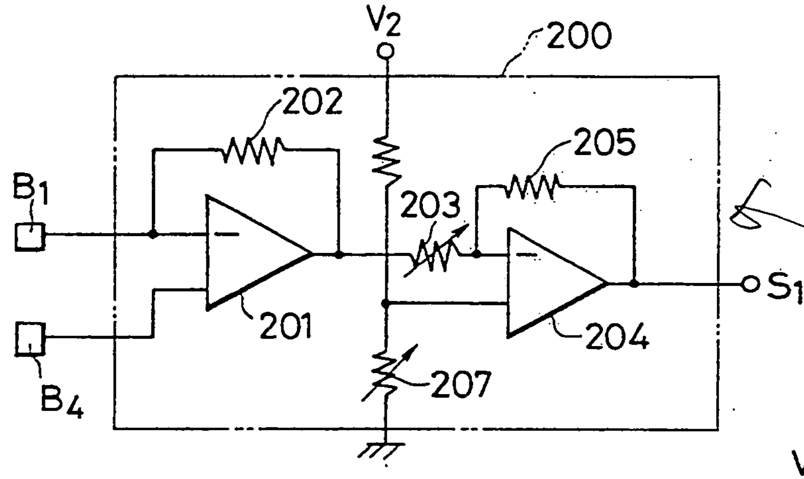

104
105
S1
S2
100A
B1
λ-DETECT
200
B2
O2 PUMP
100B
B3
300
HEATER
B4
400
SEQUENCER
500
V1
V2
ECU

FIG. 8



λ-det

FIG. 9

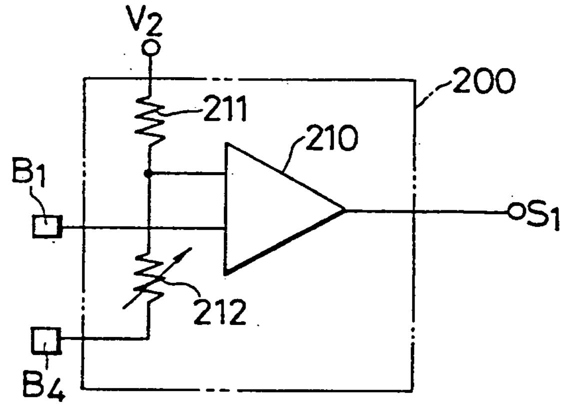


FIG. 10

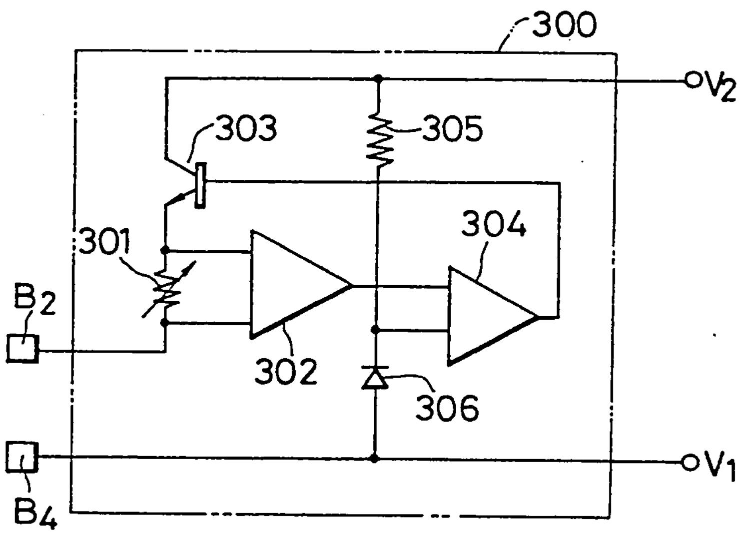
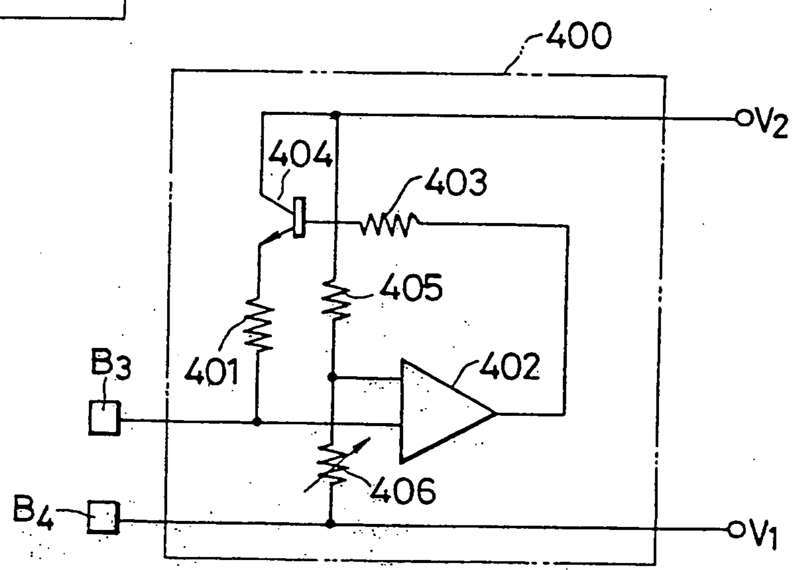


FIG. 11



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EUROPEAN SEARCH REPORT

0120423
Application number

EP 84 10 2921

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. ³)
A	EP-A-0 057 899 (HITACHI) * Figure 7; page 13 * ---	1	G 01 N 27/56
A	US-A-4 332 225 (F.G. COX) * Columns 3-7 * ---	1	
A	GB-A-1 408 377 (CENTRE DE RECHERCHES METALLURGIQUES) * Claims * ---	1	
A	US-A-4 177 770 (R.L. ANDERSON) * Whole document * ---	1	
A	US-A-4 272 331 (R.E. HETRICK) * Whole document * ---	1	
A	EP-A-0 066 228 (NGK INSULATORS) * Whole document * ---	1	TECHNICAL FIELDS SEARCHED (Int. Cl. ³)
A	DE-A-3 028 274 (NISSAN MOTOR) * Whole document * ---	1	G 01 N 27/56
P,A	WO-A-8 304 101 (MARATHON MEDICAL EQUIPMENT CORP:) * Whole document * -----	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	25-06-1984	CALLEWAERT-HAEZEBROU

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